U.S. ARMY

Technical Memorandum 3-65

RELIABILITY OF TEMPORARY THRESHOLD SHIFTS CAUSED BY REPEATED IMPULSE-NOISE EXPOSURES

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David C. Hodge
R. Bruce McCommons   Raymond F. Blackmer

February 1965
AMCMS Code 5011.11.841

HUMAN ENGINEERING LABORATORIES

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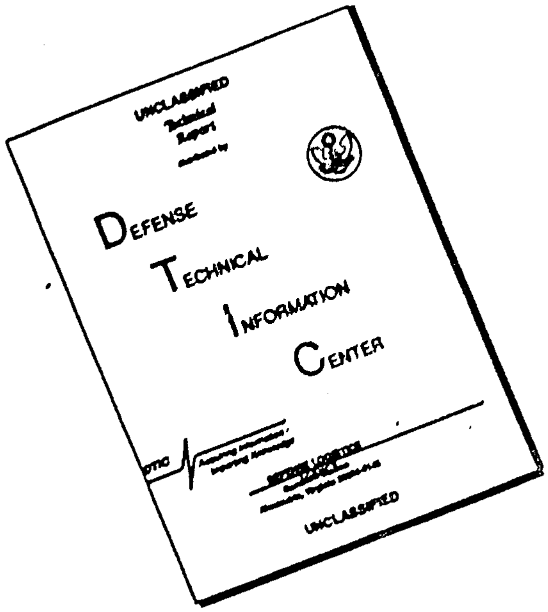

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RELIABILITY OF TEMPORARY THRESHOLD SHIFTS CAUSED BY REPEATED IMPULSE-NOISE EXPOSURES

David C. Hodge
R. Bruce McCommons Raymond F. Blackmer

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APPROVED:
JOHN [illegible] WEISZ
Technical Director
Human Engineering Laboratories

U. S. ARMY HUMAN ENGINEERING LABORATORIES
Aberdeen Proving Ground, Maryland

ABSTRACT

Twenty-two subjects were exposed to the same gunfire-noise condition nine times. Their auditory thresholds were measured at six frequencies from 500 to 6000 cycles per second before and after exposure, and all temporary threshold shifts (TTSs) were converted to TTS_2 for ease of comparison. Fluctuations in mean TTS_2 were five dB or less for all frequencies across the nine exposures, but individual differences were large and the reliability coefficients were small. It was concluded that, while repeated-measurement experimental designs appear appropriate for impulse-noise studies, group data are more meaningful than data for individual subjects. Very small samples of subjects should not be used for such studies, because it is important to be able to generalize the results to the Army as a whole.

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RELIABILITY OF TEMPORARY THRESHOLD SHIFTS

CAUSED BY REPEATED IMPULSE-NOISE EXPOSURES

INTRODUCTION

The U. S. Army Human Engineering Laboratories (HEL) are studying how exposure to impulse noise (e.g., gunfire) affects human hearing and behavior, because temporary or permanent decrements in auditory acuity, or noise-induced decrements in human performance, may be expected to affect the ability of Army personnel to carry out their assigned tasks.

Most studies in the literature that have compared two or more impulse-noise conditions have exposed the same subjects to repeated noises. The primary advantages of this procedure are that (a) each subject serves as his own control, and (b) fewer subjects are required than if a different group were used for each noise-exposure condition. However, repeated-measurements experimental designs do require that certain assumptions be met.

The most important assumption impulse-noise studies make is that noise exposures do not permanently alter the subjects. In other words, when subjects have been exposed to an impulse-noise source, have had temporary changes in their auditory thresholds (temporary threshold shift -- TTS), and have recovered to their pre-exposure hearing levels, they are, in fact, the same people they were before the noise exposure. That is, if they were exposed to the same noise source again for the same exposure, the effect on their hearing would be the same within certain limits. Conversely, if a given subject experienced no TTS on one exposure, subsequent exposures should have the same effect. This assumption should hold either for individual subjects, for the group mean TTS, or for both.

When subjects are exposed to the same noise condition repeatedly, there are four possible outcomes. First, the TTS may be the same each time. Second, the amount of TTS may fluctuate randomly, which would simplify the experimental procedures for evaluating several different noise conditions with a repeated-measurements experimental design. Third, TTS may decrease progressively with repeated exposures, as Loeb and Fletcher (12) suggested. Fourth, TTS may increase progressively. If either of these two latter outcomes occurred, then elaborate randomization and/or counterbalancing procedures would have to be incorporated into the experimental

design to equalize the "order effects" for all conditions in some random or systematic fashion. Or, and perhaps more advisable, independent groups of subjects would have to be used for each noise condition studied. Obviously, therefore, the reliabilities of individual and group TTS are very important in designing impulse-noise studies.

Fletcher and Loeb (11, 12) have already studied the reliability of TTS after repeated exposures to continuous noise, intermittent noise, and clicks, and Coles (3) has evaluated TTS reliability for gunfire exposures. Loeb and Fletcher (11) found significant reliability coefficients ranging from .55 to .66 between combinations of TTS on three exposures to clicks. They also found (12) non-significant reliability coefficients for combinations of six exposures to continuous noise, but significant reliability coefficients for combinations of six exposures to intermittent noise. There was a significant, progressive decline in mean TTS for the intermittent-noise condition, but no significant trend for the continuous-noise exposure.

Coles (3) reported that TTS declined progressively in two subjects after seven high-intensity gunfire exposures (each 20 impulses with peak SPL of 177 dB re 0.0002 microbar). However, he gave a warning before each shot was fired, and he believed the warning activated the acoustic reflex and thus provided some protection from the effects of noise. Apparently, if this explanation of the results is correct, the acoustic reflex became more effective over the course of the seven exposures. As further evidence that the acoustic reflex was involved, Coles followed the seventh exposure <u>with</u> warning signal by additional exposures <u>without</u> warning signal; and the TTS <u>increased to the level found on the first exposure</u>.

In the HEL studies (7) it has usually been desirable to avoid activating the acoustic reflex. Therefore we have not given any warning signal before firing the gun (impulse-noise source).

This study's purpose was to determine the reliability of TTS after repeated exposures to the same gunfire-noise condition. It was desired to determine the group reliability as well as individual reliability. It was hypothesized at the outset that (a) there would be significant differences among the TTS at the various audiometric testing frequencies used, as there have been in most other studies, and (b) the TTS experienced by different subjects would differ significantly, since it is well known that there are individual differences in susceptibility.

METHOD

The apparatus, and the procedures for selecting subjects (Ss) and conducting noise exposures have already been described in detail in HEL Technical Memorandum 15-64 (7). Therefore, the description of method here will be abbreviated considerably.

Subjects

Subjects for the TTS-reliability study were 29 enlisted men from various stations in the Third Army Area. They were assigned to temporary duty at HEL for the duration of the study (about six weeks). Their ages ranged from 18 to 23 years (mean age, 21.5 years), and length of service ranged from 6 to 23 months (mean length of service, 10.7 months). These enlisted men had been screened by medical personnel at their home stations to insure that they were free of chronic otolaryngological diseases, and to insure that their hearing levels did not exceed 15 dB (re American Standards Association [ASA] audiometric zero) at test frequencies of 500, 1000, 2000, 3000, 4000, and 6000 cycles per second (cps) in either ear.

Apparatus

Audiometric Testing Facilities

Two Rudmose ARJ-4 automatic (discrete-frequency, Békésy-type) audiometers were used to test the Ss' hearing levels at frequencies of 500, 1000, 2000, 3000, 4000, and 6000 cps. These instruments had been modified by the addition of two resistors and a selector switch so that the original range of hearing levels could be attenuated by 20, or 40 dB, if desired. Audiograms were typically given with the 20-dB attenuation setting, in order to measure hearing levels of Ss whose hearing was considerably better than the ASA audiometer-zero value. Each audiometer was used in a special testing room in which the maximum sound-pressure levels (SPL) were well below the limits set by the ASA standard for audiometer rooms (1).

Fig. 1. NOISE EXPOSURE SITE
(Machine-gun noise source at left, subject in center, test director and firing controls at right.)

Impulse-Noise Source and Noise Exposure

The impulse-noise source was a standard belt-fed M60 machine gun (7.62mm NATO cal.) with the flash hider and bipod removed. The gun was mounted horizontally on a rigid test stand, with its muzzle about 62 inches above ground. Standard M80 Ball ("live") ammunition was fired in the gun, the bullets impacting on a berm located about 200 yards from the muzzle. The rate of fire was controlled by an electronic device which allowed firing one round at a time. The arrangement of the noise-exposure site is shown in Figure 1.

The impulse-noise exposure consisted of 50 impulses (rounds), delivered five seconds apart. The S's ear canal was oriented normal to (i.e., toward) the gun muzzle on an azimuth of 255° from the direction of fire, at a point where the peak SPL was 155 dB (re 0.0002 microbar). This exposure condition was selected on the basis of preliminary investigations by Hodge et al. (7).

Procedure

First the Ss were given a briefing explaining the purpose and procedures of the study. Then, before the first noise exposure, the Ss were trained to use the Rudmose automatic audiometer. Each S took at least six complete audiograms. During audiometric training, the Ss also filled out a personal history form describing both their history of otolaryngological diseases and their previous exposure to noise.

For a noise-exposure session, a group of five or six Ss was transported from their billets to the noise-exposure site, where the Ss were tested individually. Immediately after taking a complete pre-exposure audiogram (both ears), the S was seated in a chair by the machine gun. Chair height was adjusted to bring the S's ear to the level of the muzzle. Then the S was placed so his left ear was at a predetermined point where the desired peak SPL occurred. A muff-type hearing protector was placed over his right ear. The S was instructed to keep his head in contact with a head rest during the exposure, so his ear position would remain constant. Finally, the machine gun was loaded with a belt of 50 rounds, and the automatic timing and firing circuit was activated to give the noise exposure. After the last round, the S went back into the audiometric testing room for a complete post-exposure audiogram, which began 35 seconds after the last round was fired. Following the audiogram, the S walked back to a rest area about 200 yards from the exposure site, and the next S came to the site to repeat the same procedure. At the end of a session, the Ss were returned to their billets.

Most tests for recovery from any temporary changes in hearing level were given solely to establish that recovery had, in fact, occurred. Twenty-four hours after exposure the Ss reported individually to a testing facility near their billets, where a recovery audiogram was given. In special cases, such as when the noise exposure produced a TTS of 40 dB or more, the S was tested at four- to eight-hour intervals, in the same facility, to measure recovery functions for these large TTSs.

Subjects were not exposed to noise again until they had recovered to at least within five dB of their pre-exposure hearing levels. Because of inclement weather and other scheduling problems, it was not possible to keep the time between exposures the same for all Ss. The time between exposures varied at random from 2 1/2 to 7 days.

Both the pre- and post-exposure audiograms were recorded on the same audiogram record card to help determine how much TTS the noise exposure produced. In scoring the audiograms, the difference in hearing level between the pre- and post-exposure tests was first measured to the nearest 2.5 dB. Then all of the differences were converted forward or backward in time to the TTS that would have occurred at two minutes after exposure (TTS_2), using a conversion chart published earlier by Hodge et al. (7) and derived from a graph prepared by Kryter (9) from data of Ward, Glorig, and Sklar (13). This conversion made it easier to compare TTS at the various test frequencies.

RESULTS

Initially there were 29 Ss in the study. One was disqualified during the audiometric training because his hearing levels in both ears exceeded 15 dB at 6000 cps. Five were dropped after the first exposure because they had TTS of 40 dB or more. One additional S's data were eliminated when he deliberately attempted to fake his audiograms. Therefore the data about TTS reliability are based on nine exposures of 22 Ss to the same noise condition. Means and standard deviations of these 22 Ss' hearing levels before the first exposure are shown in Table 1.

TABLE 1

Means and Standard Deviations
of the Pre-Exposure Hearing Levels (N = 22)
(dB re ASA audiometer zero reference value)

Ear	Frequency	Mean	Standard Deviation
Left	500	-9.09	5.48
	1000	-6.36	7.27
	2000	-3.18	7.57
	3000	2.50	7.52
	4000	3.64	8.48
	6000	4.32	11.68
Right	500	-7.27	8.12
	1000	-6.14	11.12
	2000	-5.45	9.75
	3000	0	8.02
	4000	2.73	9.35
	6000	2.73	11.72

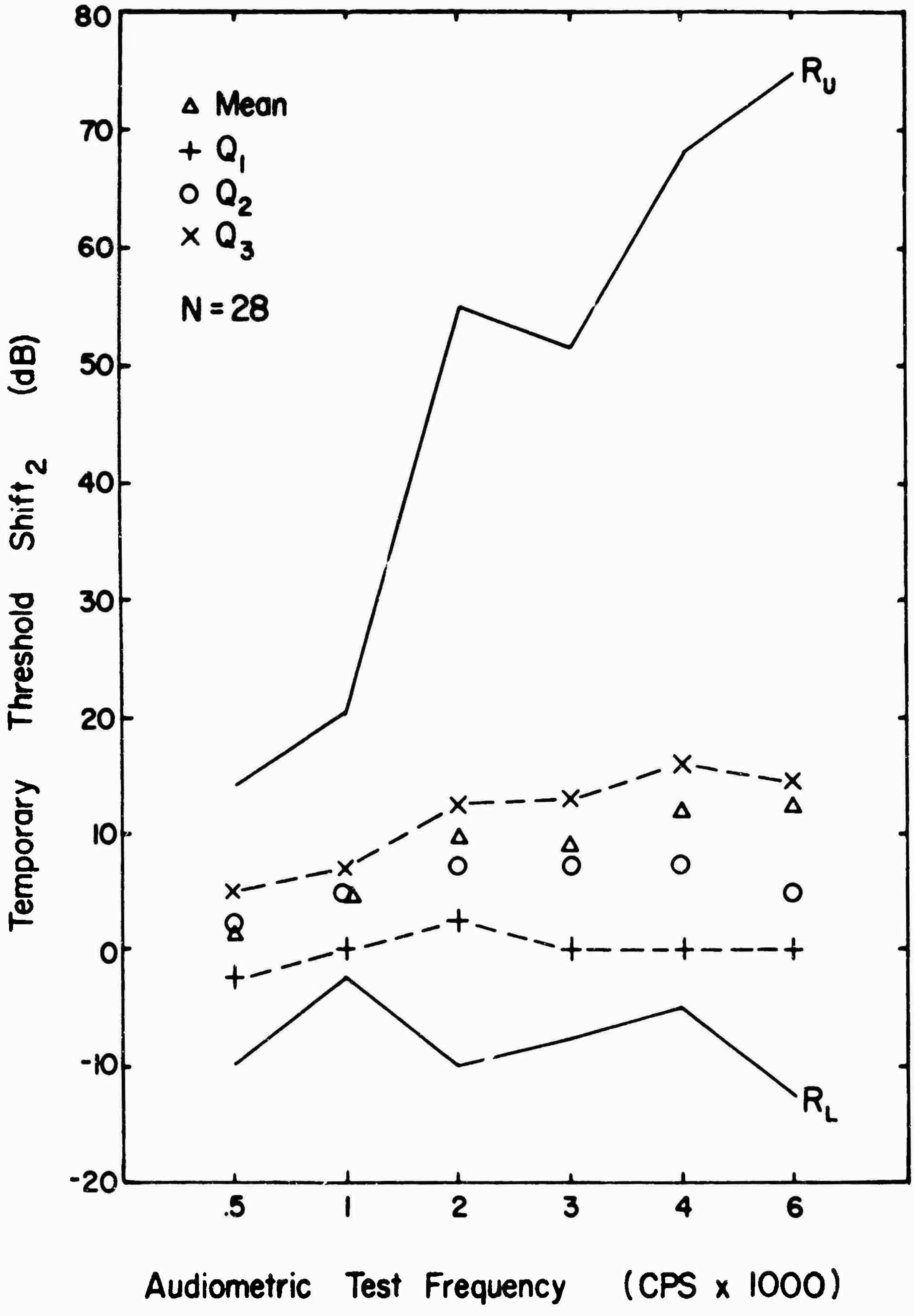

Fig. 2. MEANS, QUARTILES, AND RANGES OF TTS_2 FOR ALL SUBJECTS GIVEN THE FIRST IMPULSE-NOISE EXPOSURE (N = 28)

Figure 2 gives the means, quartiles, and ranges of TTS_2 at each of six audiometric test frequencies for all 28 Ss actually exposed on the first noise exposure. These data are presented only to show how the particular noise condition used in this study affected the entire group of Ss.

Table 2 and Figure 3 give the group means and standard deviations for TTS_2 at each of the six audiometric test frequencies for each of the nine noise exposures. These data illustrate that, within a given test frequency, the TTS_2s showed little change in either means or standard deviations.

The TTS_2 data were evaluated by means of an A x B x S analysis of variance described by Lindquist (10, p. 237). This analysis is summarized in Table 3. All of the main effects and testable interaction effects were significant, at varying levels.

Pearson test-retest reliability coefficients (5, p. 435 ff.) for all combinations of exposures at each audiometric test frequency were calculated by the Computing Laboratory, U. S. Army Ballistics Research Laboratories, and are shown in Appendix A. Reliability coefficients were also obtained for all combinations of test frequencies at each noise exposure, as shown in Appendix B.

The incidence of statistically significant reliability coefficients (.05 level of confidence) for the six test frequencies is shown in Table 4, while that for exposures is shown in Table 5.

To evaluate individual differences in TTS_2 among the Ss, a standard deviation for each S was computed from the TTS_2 at all frequencies and for all exposures. That is, each of the 22 standard deviations was based on TTS_2s at the 54 combinations of test frequencies and exposures. These 22 standard deviations are shown in Table 6, arranged in order of magnitude from greatest to least. This array suggested that Ss could be sorted into three groups by their degree of variability: (a) the two Ss having standard deviations of 10.29 and 10.16, (b) the seven Ss for whom the range was 7.89 to 6.45, and (c) the 13 Ss whose standard deviations ranged between 5.39 and 3.39. Appendix C gives graphs showing the TTS_2 for all frequencies and exposures for one S in each of these three arbitrary groups.

TABLE 2

Means and Standard Deviations of TTS_2 (Decibels)
for Six Audiometric Test Frequencies and Nine Noise Exposures

Exposure		Audiometric Test Frequency (cps) 500	1000	2000	3000	4000	6000
1	M	2.04	4.32	6.25	4.43	6.66	4.93
	SD	5.79	5.13	7.59	6.35	9.66	8.37
2	M	4.23	4.48	7.84	5.16	8.29	6.05
	SD	3.18	4.34	5.37	7.28	9.90	13.01
3	M	1.79	3.57	5.82	3.52	4.91	1.41
	SD	3.70	5.05	6.56	7.99	8.12	8.79
4	M	1.16	3.73	4.77	3.36	4.02	2.95
	SD	3.99	6.74	6.31	9.01	8.28	8.17
5	M	3.89	3.52	5.70	3.98	3.52	2.91
	SD	3.48	6.20	5.92	6.68	9.83	9.48
6	M	0.14	4.11	8.41	4.07	[illegible]	1.77
	SD	3.91	5.10	5.21	5.84	[illegible]	9.11
7	M	1.50	4.36	7.14	0.41	5.54	2.48
	SD	2.97	5.61	5.83	5.44	9.68	8.69
8	M	2.16	3.93	6.36	5.20	6.20	5.73
	SD	3.56	3.75	5.44	6.38	9.51	6.60
9	M	2.48	3.07	5.68	3.39	4.89	4.29
	SD	4.22	3.60	5.35	6.59	8.10	8.74

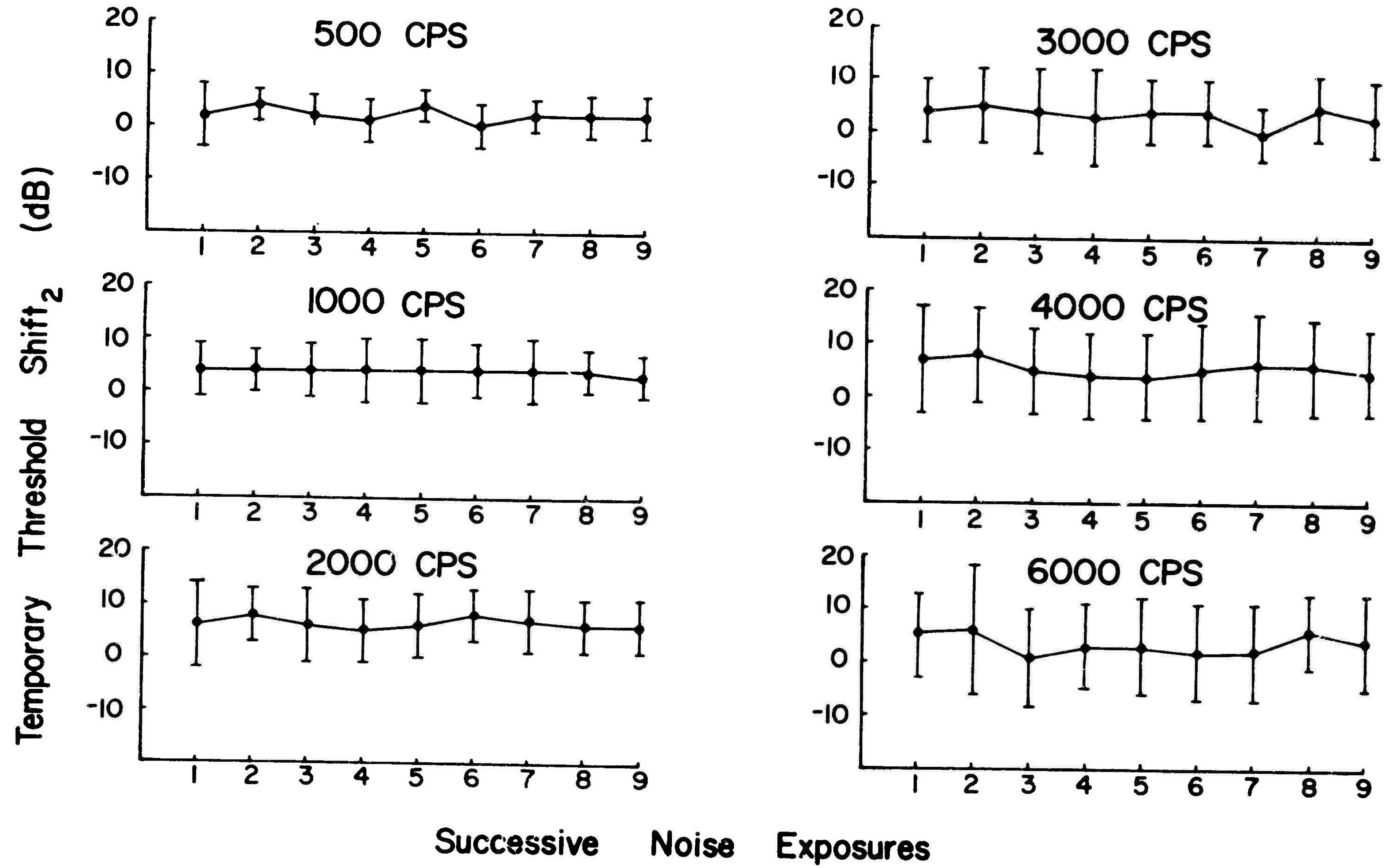

Fig. 3. MEANS AND STANDARD DEVIATIONS OF TTS_2 AT THE SIX AUDIOMETRIC TEST FREQUENCIES FOR ALL NINE NOISE EXPOSURES

TABLE 3

Summary of Analysis of Variance

Source	df	Mean Square	F	p
Audiometric Test Frequencies (F)	5	391.17	3.31	<.01
Noise Exposures (E)	8	98.78	2.01	<.05
Subjects (Ss)	21	687.34	29.56	<.001
F x E	40	32.59	1.40	<.05
F x Ss	105	118.06	5.08	<.01
E x Ss	168	49.02	2.11	<.01
F x E x Ss	840	23.25	--	--
Total	1187			

TABLE 4

Incidence of Statistically Significant Test-Retest Reliability Coefficients Between Combinations of Nine Exposures for Six Test Frequencies

Audiometric Test Frequency (cps)	No. of Significant Coefficients[a]
500	7
1000	12
2000	29
3000	23
4000	29
6000	20

[a] Out of a total of 36 combinations of exposures.

TABLE 5

Incidence of Statistically Significant Test-Retest Reliability Coefficients Between Combinations of Six Test Frequencies for Nine Noise Exposures

	Frequency (cps)					
Frequency (cps)	500	1000	2000	3000	4000	6000
500	--	3	3	1	1	1
1000	3	--	3	0	1	0
2000	3	3	--	4	0	2
3000	1	0	4	--	8	7
4000	1	1	0	8	--	6
6000	1	0	2	7	6	--

TABLE 6

Standard Deviations of TTS_2 for Individual Subjects
Arranged in Order of Magnitude
and Arbitrarily Divided into Three Groups

Category	Subject No.	Standard Deviation
Large Variability	14	10.29
	18	10.16
Moderate Variability	29	7.89
	8	7.77
	28	7.58
	11	7.26
	10	7.21
	2	6.52
	25	6.45
Least Variability	5	5.39
	19	5.09
	7	5.08
	16	4.87
	26	4.80
	12	4.51
	3	4.51
	4	4.48
	27	4.37
	23	4.09
	17	4.05
	21	3.87
	24	3.39

DISCUSSION

The distributions of TTS_2 for the group of 28 Ss given the first noise exposure (Fig. 2) were essentially the same as those found in a preliminary study by Hodge et al. (7).

The means and standard deviations of TTS_2 in Table 2 and Figure 3 show that neither of these values has a systematic trend for any of the six test frequencies. (In Figure 3 the TTS_2 values were rounded to the nearest whole number for ease of plotting on the condensed scale.) Mean TTS_2 increased slightly from the first to the second noise exposure for all frequencies, decreased slightly between the second and third exposures, and decreased slightly again between the eighth and ninth exposures. But aside from these short-term effects, the means showed no other obvious trends. Neither did the standard deviations.

In the analysis of variance (Table 3), the frequencies main effect was significant at the .01 level of confidence, as expected. The mean TTS_2s for 2000, 3000, and 4000 cps were somewhat larger than those for 500, 1000, and 6000 cps, as they were in other experiments carried out at HEL.

The Ss main effect was also significant, as predicted from the known (2) large differences in individual susceptibility to the effects of noise, especially gunfire.

The significance of the exposures main effect reflects the fact that, although there were no obvious trends in the mean TTS_2, there were differences among the various exposures. Figure 3 shows that the largest difference among the means at any given frequency was five dB. The noise exposures main effect barely reached significance at the .05 level of confidence.

The significant frequencies-x-exposures interaction suggests that the TTS_2s of the six frequencies did not bear the same relationship to one another on all of the exposures. This effect was barely significant at the .05 level of confidence. The significant interactions of frequencies and exposures with Ss indicate that the relative amounts of TTS_2 for the various frequencies and exposures differed among the Ss, a not unexpected finding.

An examination of the test-retest reliability coefficients shown in Tables 4 and 5 and Appendixes A and B reveals something about the reliability of TTS_2 within frequencies across the nine exposures, and between frequencies for the various exposures. From the incidence of significant reliabilities shown in Table 4, it would appear that the most reliable test frequencies were 2000 and 4000 cps, since 29 out of a possible 36 reliability coefficients were significant at the .05 level of confidence for both of these frequencies. The order of reliability from best to worst, using the incidence of significance as an index, was 2000 and 4000 cps (equal), 3000, 6000,

1000, and 500 cps. Most of the reliability coefficients, even though significant, were small. Since a reliability coefficient of .70 accounts for only 49 percent of the variance, the coefficients would have to be very large, i.e., around .90, before any real confidence could be placed in their predictive value. The findings in this case indicate that, although the group means were fairly stable, the individual S's TTSs varied considerably. This led to the conclusion that repeated-measurement experimental designs could be used where the interpretation of results is based on group-mean TTS. However, very small groups of Ss should not be used in studies conducted to evaluate impulse-noise hazards, i.e., the hazards of a new weapon system, or to develop damage-risk criteria. It is likely that very "unreliable" Ss may be selected randomly. If this should happen the results could not be generalized to the Army as a whole. No attempt will be made here to specify the minimum number of Ss that should be used in impulse-noise studies, other than to point out that the consensus of the members of the Committee on Hearing and Bio-Acoustics (CHABA) Working Group 46 was that at least 12 Ss should be used in this kind of investigation (8).

The reliability coefficients given in Appendix B and summarized in Table 5 -- reliability of TTS_2 for the six audiometric test frequencies within noise exposures -- indicated that there were significant correlations between 3000 and 4000 cps for eight out of nine exposures, between 3000 and 6000 cps for seven exposures, and between 4000 and 6000 cps for six exposures. While it might appear that the TTS_2 at one test frequency could be predicted from that occurring at another frequency, the coefficients themselves (Appendix B) do not support such a conclusion. For example, the coefficients between 3000 and 4000 cps ranged between .30 and .69. These values mean that only about 9 to 49 percent of the total variance has been accounted for. It was pointed out above that correlation coefficients on the order of .90 would be required before great confidence could be placed in the relationship.

This study's finding that there were few significant correlations between the high and low frequencies agrees with the findings of Fletcher (4).

The mean TTS_2s shown in Table 2 and Figure 3 are all very small, i.e., less than 10 dB. This might suggest that the TTSs were not real but, rather, simply reflected differences in hearing level on repeated audiograms. (Other investigators, e.g., Loeb and Fletcher [12], obviated this problem by using a noise exposure which produced a much larger mean TTS_2.) To test this possibility, the difference in hearing levels was computed for the 22 Ss on the fifth and sixth training audiograms. These two audiograms had been given about 30 minutes apart during the training session prior to the first noise exposure. The mean differences in hearing level ranged from 0.71 to 1.67 dB, depending on the test frequency. Since they were all less than 2 dB, it is assumed that the mean hearing-level changes between pre- and post-exposure audiograms in this study were really noise-induced temporary threshold shifts.

The impulse-noise studies at HEL have persistently and rather frequently yielded negative TTS_2s. A negative TTS, if real, indicates that noise exposure has produced an improvement in hearing level (increased sensitivity). This finding obviously runs counter to what would normally be expected. Some writers, such as Hecker and Kryter (6), have dealt with this problem by ignoring it, i.e., they arbitrarily called any TTS with a negative sign zero. In so doing, they often assumed that the S was suffering from tinnitus, that he was unable to track the audiometer tone properly, and thus that the post-exposure audiometric tracing was on the "wrong" side of the pre-exposure trace.

In our studies, negative TTSs have been observed with great regularity, and sometimes in large magnitude. In the present study the largest negative TTS observed was 12.5 dB, and most of them were in the range from 2.5 to 7.5 dB. However, in some of the earlier preliminary investigations, we observed negative TTSs on the order of 20 to 30 dB.

While a negative TTS does run counter to the expected effect of a noise exposure, and has the effect of reducing the mean TTS associated with a given noise-exposure condition, we believe it is better to live with the negative TTSs than to ignore them. In the future, perhaps, we may be able to determine whether or not negative TTSs really represent improved auditory acuity or whether they are an indication that the S is suffering from tinnitus or some other condition. Perhaps a procedure can be found to supplement the post-exposure audiogram, to give a more sensitive measure of the S's auditory acuity after noise exposure.

SUMMARY AND CONCLUSIONS

To study the reliability of temporary threshold shifts (TTS), 22 Army enlisted men were trained in the use of the Rudmose ARJ-4 automatic audiometer and subsequently exposed nine times to the same noise condition. The noise exposure consisted of 50 rounds fired from an M60 machine gun, five seconds between rounds, with the S's left ear canal oriented normal to the gun muzzle at a point where the peak SPL was 155 dB (re 0.0002 microbar). Measurements of TTS at six test frequencies between 500 and 6000 cps were converted to TTS_2 for ease of comparison.

The overall fluctuation in mean TTS_2 was five dB or less for all six test frequencies, and fluctuations in the standard deviations were likewise small. There were no obvious upward or downward trends in mean TTS_2 across the nine exposures. Individual differences in TTS_2 were quite large, however, and the reliability coefficients in general were small.

The findings led to these conclusions:

a. Repeated-measurement experimental designs are appropriate for use in impulse-noise studies when the interpretation is based on group mean TTS and when an adequate number of Ss is used. Larger numbers of Ss will improve generalizations to the Army as a whole.

b. The most reliable (repeatable) TTSs across the noise exposures were those for the 2000 and 4000 cps test frequencies.

c. Within noise exposures, the largest numbers of significant reliability coefficients were between 3000 and 4000, 3000 and 6000, and 4000 and 6000 cps. However, the coefficients were too small to be of value in predicting TTS at one frequency from that occurring at another.

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APPENDIX A

Test-Retest Reliability Coefficients for All Possible Combinations of Nine Noise Exposures and Each of Six Audiometric Test Frequencies

500 cps

Exposures	Exposures 1	2	3	4	5	6	7	8	9
1	--	.02	.45*	.39	.42*	.51*	-.01	.23	.18
2	.02	--	-.22	.03	.36	.13	.79*	-.12	-.29
3	.45*	-.22	--	.15	.11	.30	-.35	.48*	.33
4	.39	.03	.15	--	.13	.42*	.26	.36	.10
5	.42*	.36	.11	.13	--	.09	.25	.22	.30
6	.51*	.13	.30	.42*	.09	--	-.11	.34	-.04
7	-.01	.79*	-.35	.26	.25	-.11	--	-.05	-.15
8	.23	-.12	.48*	.36	.22	.34	-.05	--	.64*
9	.18	-.29	.33	.10	.30	-.04	-.15	.64*	--

* $\underline{p} < .05$

1000 cps

Exposures	Exposures 1	2	3	4	5	6	7	8	9
1	--	.55*	.39	-.01	.47*	-.14	.11	.09	-.13
2	.55*	--	.42*	.39	.55*	.41*	.30	.25	.10
3	.39	.42*	--	.21	.62*	.01	-.08	.55*	-.20
4	-.01	.39	.21	--	.53*	.56*	.49*	.08	.03
5	.47*	.55*	.62*	.53*	--	.34	.18	.42*	-.18
6	-.14	.41*	.01	.56*	.34	--	.37	.08	.29
7	.11	.30	-.08	.49*	.18	.37	--	.11	.43*
8	.09	.25	.55*	.08	.42*	.08	.11	--	.30
9	-.13	.10	-.20	.03	-.18	.29	.43*	.30	--

* $\underline{p} < .05$

2000 cps

Exposures	1	2	3	4	5	6	7	8	9
1	--	.45*	.68*	.55*	.70*	.45*	.16	.50*	.60*
2	.45*	--	.62*	.42*	.46*	.52*	.49*	.68*	.77*
3	.68*	.62*	--	.49*	.57*	.59*	.68*	.69*	.65*
4	.55*	.42*	.49*	--	.40	.40	.21	.31	.37
5	.70*	.46*	.57*	.40	--	.73*	.21	.49*	.50*
6	.45*	.52*	.59*	.40	.73*	--	.64*	.51*	.60*
7	.16	.49*	.68*	.21	.21	.64*	--	.68*	.42*
8	.50*	.68*	.69*	.31	.49*	.51*	.68*	--	.51*
9	.60*	.77*	.65*	.37	.50*	.60*	.42*	.51*	--

Column heading: Exposures

* $p < .05$

3000 cps

Exposures	1	2	3	4	5	6	7	8	9
1	--	.43*	.30	.29	.29	.29	.39	.21	.46*
2	.43*	--	.50*	.53*	.36	.60*	.61*	.35	.53*
3	.30	.50*	--	.50*	.56*	.79*	.40	.69*	.84*
4	.29	.53*	.50*	--	.51*	.49*	.46*	.20	.39
5	.29	.36	.56*	.51*	--	.56*	.09	.43*	.52*
6	.29	.60*	.79*	.49*	.56*	--	.51*	.51*	.74*
7	.39	.61*	.40	.46*	.09	.51*	--	.22	.61*
8	.21	.35	.69*	.20	.43*	.51*	.22	--	.57*
9	.46*	.53*	.84*	.39	.52*	.74*	.61*	.57*	--

Column heading: Exposures

* $p < .05$

4000 cps

Exposures	Exposures 1	2	3	4	5	6	7	8	9
1	--	.34	.38	.58*	.49*	.60*	.67*	.47*	.65*
2	.34	--	.55*	.17	.64*	.57*	.44*	.76*	.40
3	.38	.55*	--	.60*	.59*	.68*	.35	.50*	.60*
4	.58*	.17	.60*	--	.41	.55*	.55*	.48*	.71*
5	.49*	.64*	.59*	.41	--	.64*	.40	.74*	.50*
6	.60*	.57*	.68*	.55*	.64*	--	.59*	.47*	.58*
7	.67*	.44*	.35	.55*	.40	.59*	--	.62*	.62*
8	.47*	.76*	.50*	.48*	.74*	.47*	.62*	--	.54*
9	.65*	.40	.60*	.71*	.50*	.58*	.62*	.54*	--

* $\underline{p} < .05$

6000 cps

Exposures	Exposures 1	2	3	4	5	6	7	8	9
1	--	.47*	.20	.07	.31	.15	.39	.59*	.49*
2	.47*	--	.64*	.09	.39	.66*	.85*	.57*	.53*
3	.20	.64*	--	-.05	.44*	.72*	.69*	.50*	.32
4	.07	.09	-.05	--	-.08	-.10	.19	-.03	.11
5	.31	.39	.44*	-.08	--	.44*	.48*	.34	.37
6	.15	.66*	.72*	-.10	.44*	--	.71*	.59*	.42*
7	.39	.85*	.69*	.19	.48*	.71*	--	.70*	.58*
8	.59*	.57*	.50*	-.03	.34	.59*	.70*	--	.50*
9	.49*	.53*	.32	.11	.37	.42*	.58*	.50*	--

* $\underline{p} < .05$

APPENDIX B

Test-Retest Reliability Coefficients
for All Possible Combinations of Six Audiometric Test Frequencies
and Each of Nine Noise Exposures

Exposure No. 1

Frequency (cps)	Frequency (cps) 500	1000	2000	3000	4000	6000
500	--	.69*	.58*	.19	-.03	.32
1000	.69*	--	.44*	.25	.11	.32
2000	.58*	.44*	--	.26	-.02	.21
3000	.19	.25	.26	--	.51*	.47*
4000	-.03	.11	-.02	.51*	--	.21
6000	.32	.32	.21	.47*	.21	--

* $p < .05$

Exposure No. 2

Frequency (cps)	Frequency (cps) 500	1000	2000	3000	4000	6000
500	--	.48*	-.14	.17	.23	-.03
1000	.48*	--	-.30	.04	.56*	.32
2000	-.14	-.30	--	.51*	-.03	.29
3000	.17	.04	.51*	--	.52*	.56*
4000	.23	.56*	-.03	.52*	--	.77*
6000	-.03	.32	.29	.56*	.77*	--

* $p < .05$

Exposure No. 3

Frequency (cps)	Frequency (cps)					
	500	1000	2000	3000	4000	6000
500	--	.04	.36	.32	.29	.35
1000	.04	--	.18	.06	.02	-.15
2000	.36	.18	--	.61*	.36	.29
3000	.32	.06	.61*	--	.56*	.48*
4000	.29	.02	.36	.56*	--	.71*
6000	.35	-.15	.29	.48*	.71*	--

* $p < .05$

Exposure No. 4

Frequency (cps)	Frequency (cps)					
	500	1000	2000	3000	4000	6000
500	--	.06	.43*	.16	.26	-.02
1000	.06	--	.45*	.37	.35	-.07
2000	.43*	.45*	--	.23	.40	.05
3000	.16	.37	.23	--	.69*	.26
4000	.26	.35	.40	.69*	--	.22
6000	-.02	-.07	.05	.26	.22	--

* $p < .05$

Exposure No. 5

Frequency (cps)	Frequency (cps)					
	500	1000	2000	3000	4000	6000
500	--	.36	.15	.37	.48*	.48*
1000	.36	--	.11	-.05	.07	-.19
2000	.15	.11	--	.65*	.33	.36
3000	.37	-.05	.65*	--	.55*	.63*
4000	.48*	.07	.33	.55*	--	.52*
6000	.48*	-.19	.36	.63*	.52*	--

* $p < .05$

Exposure No. 6

Frequency (cps)	Frequency (cps)					
	500	1000	2000	3000	4000	6000
500	--	-.06	.43*	.15	.18	-.06
1000	-.06	--	-.03	.21	.18	-.04
2000	.43*	-.03	--	.50*	.09	.22
3000	.15	.21	.50*	--	.38	.50*
4000	.18	.18	.09	.38	--	.62*
6000	-.06	-.04	.22	.50*	.62*	--

* $p < .05$

Exposure No. 7

Frequency (cps)	Frequency (cps) 500	1000	2000	3000	4000	6000
500	--	.29	-.01	.19	.13	.13
1000	.29	--	.58*	.38	.21	.60*
2000	-.01	.58*	--	.29	.39	.57*
3000	.19	.38	.29	--	.42*	.54*
4000	.13	.21	.39	.42*	--	.56*
6000	.13	.60*	.57*	.54*	.56*	--

* $p < .05$

Exposure No. 8

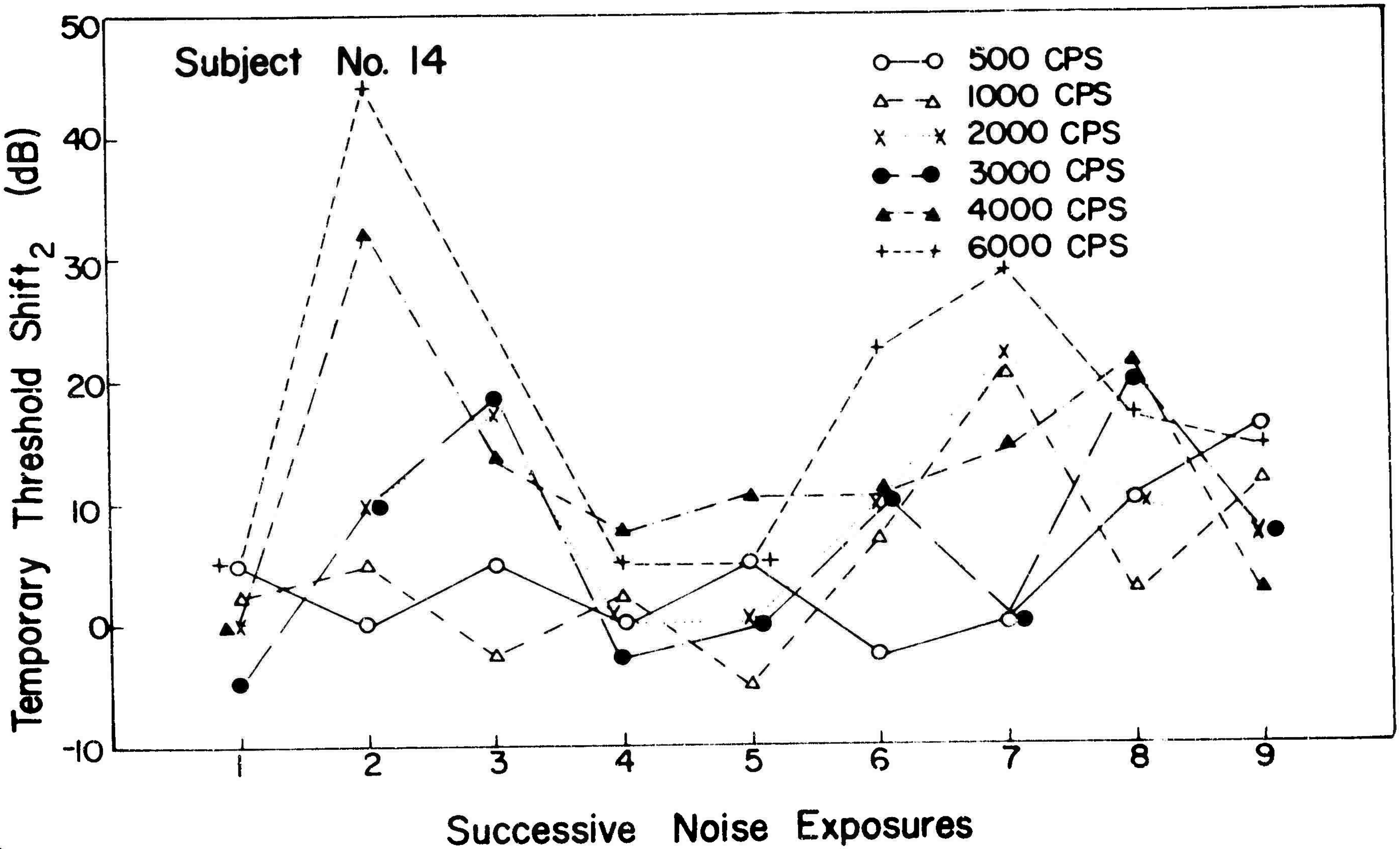
Frequency (cps)	Frequency (cps) 500	1000	2000	3000	4000	6000
500	--	.29	.28	.49*	.36	.36
1000	.29	--	.07	.36	.18	.06
2000	.28	.07	--	.36	.33	.15
3000	.49*	.36	.36	--	.64*	.53*
4000	.36	.18	.33	.64*	--	.45*
6000	.36	.06	.15	.53*	.45*	--

* $p < .05$

Exposure No. 9

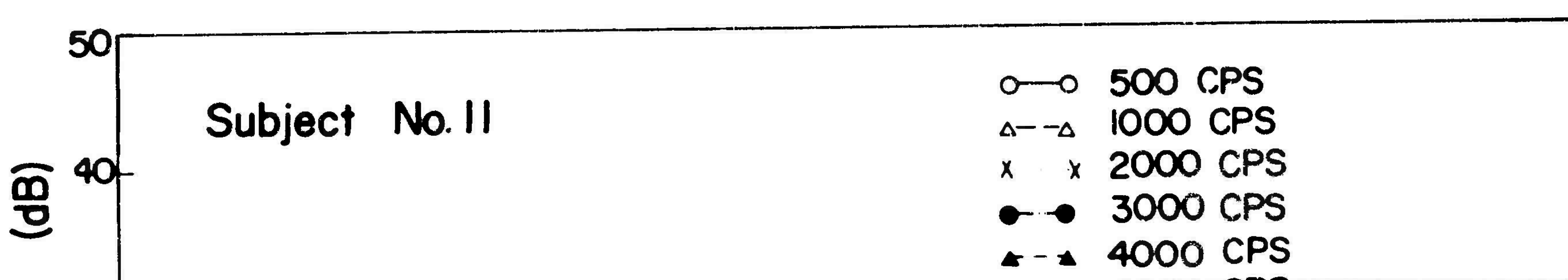
Frequency (cps)	Frequency (cps)					
	500	1000	2000	3000	4000	6000
500	--	.68*	.24	.25	.12	.37
1000	.68*	--	.08	.19	.21	.36
2000	.24	.08	--	.39	.35	.49*
3000	.25	.19	.39	--	.65*	.40
4000	.12	.21	.35	.65*	--	.25
6000	.37	.36	.49*	.40	.25	--

* $p < .05$



A

Fig. 1C. TTS_2 AT SIX TEST FREQUENCIES AND NINE NOISE EXPOSURES FOR A SUBJECT HAVING THE LARGEST AMOUNT OF VARIATION IN TTS_2



Graphs Showing Three Am

APPENDIX C

Showing Three Amounts of Variability in TTS_2 Exhibited by Subjects in This Study

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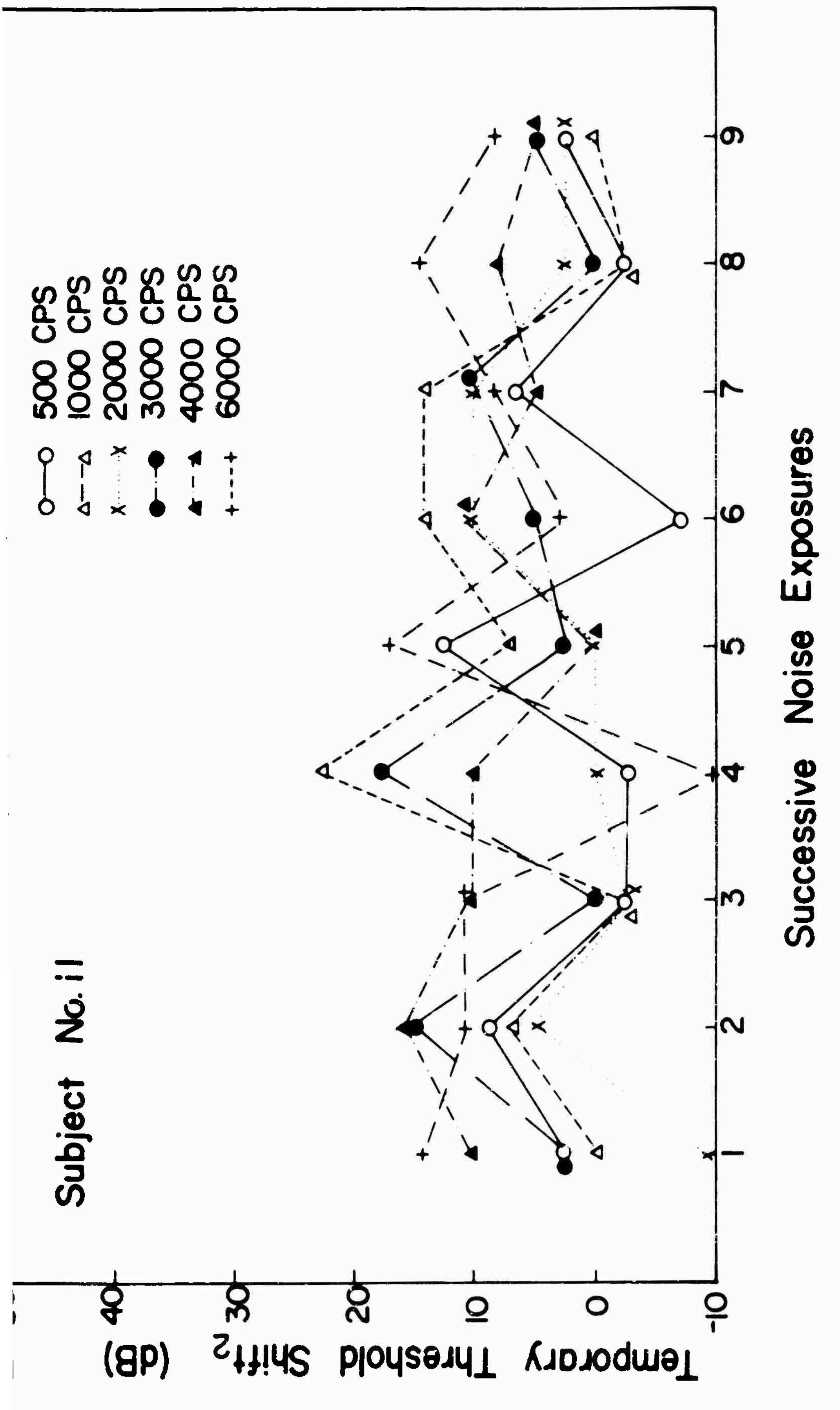
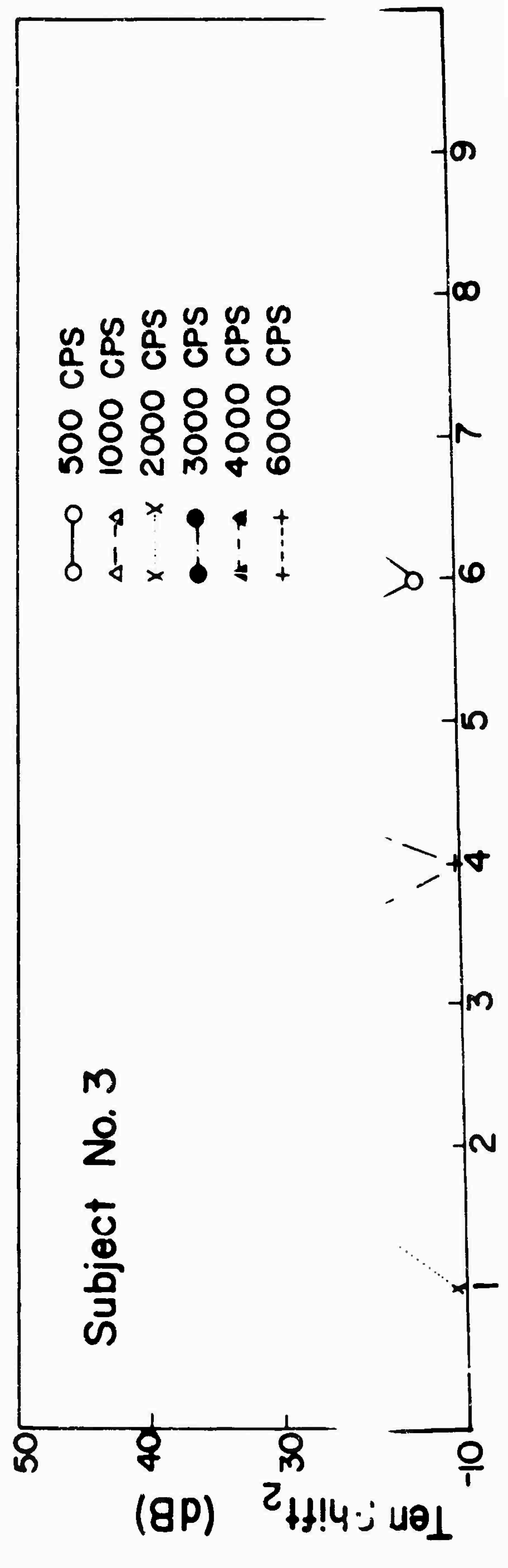


Fig. 2C. TTS_2 AT SIX TEST FREQUENCIES AND NINE NOISE EXPOSURES FOR A SUBJECT HAVING A MODERATE AMOUNT OF VARIATION IN TTS_2



B

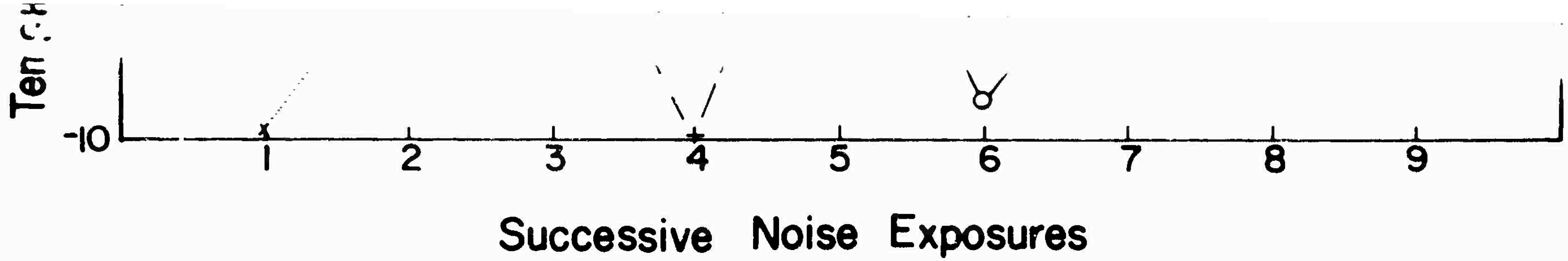


Fig. 2C. TTS_2 AT SIX TEST FREQUENCIES AND NINE NOISE EXPOSURES FOR A SUBJECT HAVING A MODERATE AMOUNT OF VARIATION IN TTS_2

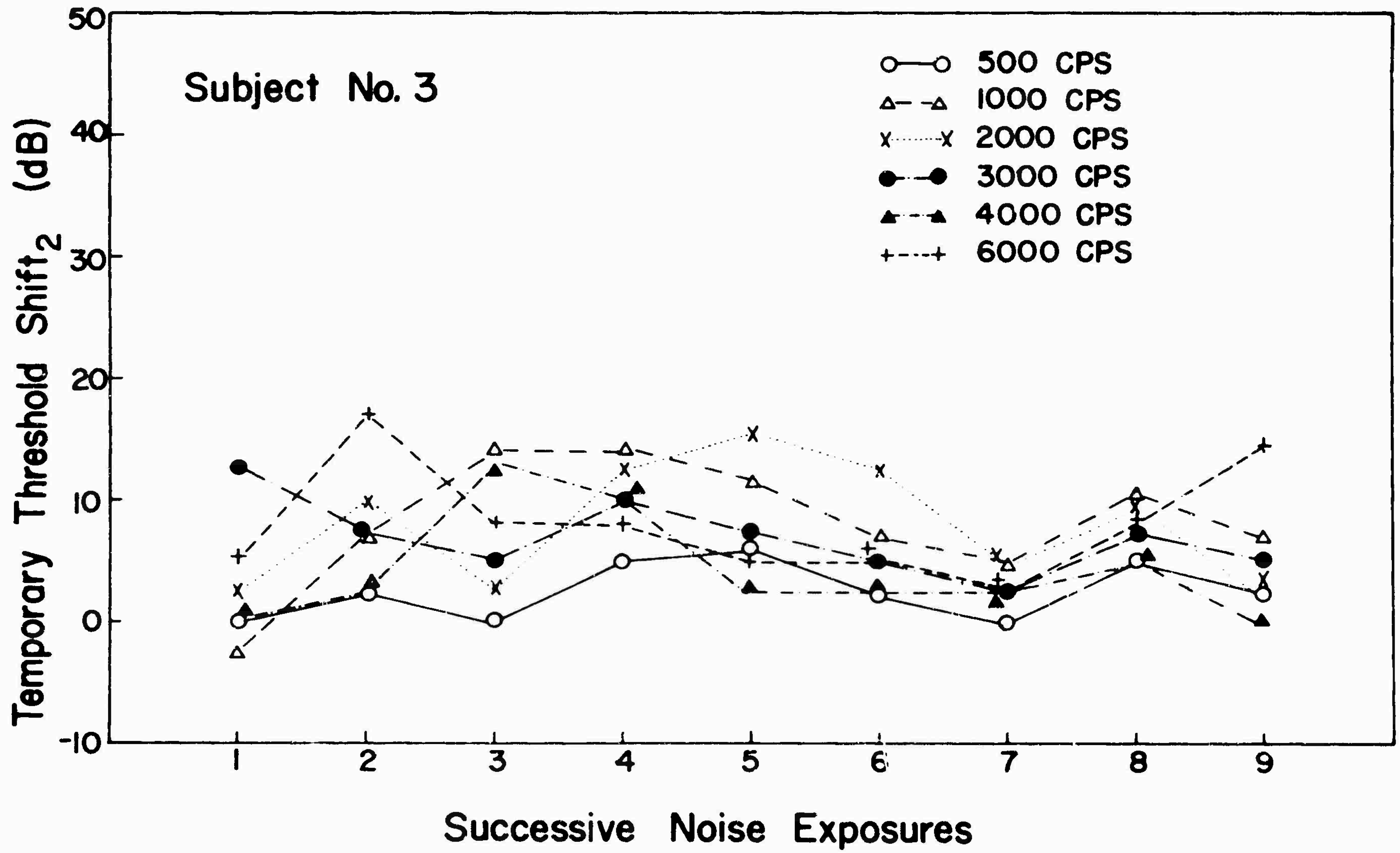


Fig. 3C. TTS_2 AT SIX TEST FREQUENCIES AND NINE NOISE EXPOSURES FOR A SUBJECT HAVING A SMALL AMOUNT OF VARIATION IN TTS_2